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Recommendations for indicator selection for Endeavour Hydrothermal vents Marine Protected Area

Recommandations concernant la sélection d'indicateurs pour la zone de protection marine du champ hydrothermal Endeavour

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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ABSTRACT

In support of the *Health of the Oceans Initiative*, Fisheries and Oceans Canada (DFO) Science has been asked to recommend scientifically defensible indicators to monitoring the achievement of the conservation objective for the Endeavour Hydrothermal Vents Marine Protected Area (EHV MPA). This paper outlines a five step Stressor Based Indicator Identification Framework to monitor human induced stressors and the ecosystem reference state. This framework evaluates human activities using a Pathways of Effects (PoE) approach to understand the extent and nature of the impacts of potential stressors on the ecosystem. All known human activities have been identified for the EHV MPA, and simplified PoEs have been carried out for each activity. These PoEs were provided as examples for discussion and future more in-depth evaluation is required to complete these PoEs and subsequent risk assessments. The broad nature of the conservation objective for the EHV MPA needs to be refined to operational level objectives that are measurable to determine candidate indicators for monitoring.

This paper recommends:

- The development of scientifically defensible indicators for monitoring the achievement of the conservation objective for EHV MPA
- Following the Stressor Based Indicator Identification Framework as described in this document to assess risks to the MPA and to select appropriate indicators for monitoringollect baseline data to evaluate natural and stressor based changes
- Develop a comprehensive reporting system to evaluate the nature and extent of human activities.

RÉSUMÉ

Pour soutenir l'initiative *Santé des Océans*, on a demandé au secteur des Sciences de Pêches et Océans Canada (MPO) de recommander des indicateurs scientifiquement défendables en vue de surveiller l'atteinte de l'objectif de conservation de la zone de protection marine du champ hydrothermal Endeavour (ZPM Endeavour). Le présent document présente un cadre en cinq étapes d'établissement des indicateurs associés aux facteurs de stress conçu pour surveiller les facteurs de stress d'origine anthropique ainsi que l'état de référence de l'écosystème. Ce cadre évalue les activités humaines à l'aide d'une approche de séquences d'effets dans le but de comprendre l'étendue et la nature des impacts des facteurs de stress possibles sur l'écosystème. On a déterminé toutes les activités humaines connues dans la ZPM Endeavour et on a exécuté des séquences des effets simplifiées pour chaque activité. Ces séquences des effets ont servi d'exemples aux fins de discussion, mais des évaluations futures plus approfondies seront nécessaires pour compléter ces séquences et les évaluations subséquentes des risques. Il importe de préciser la vaste nature de l'objectif de conservation de la ZPM Endeavour en objectifs opérationnels mesurables afin de déterminer les indicateurs possibles à surveiller.

Le présent document recommande donc les démarches suivantes :

- établir des indicateurs défendables sur le plan scientifique afin de surveiller l'atteinte de l'objectif de conservation de la ZPM Endeavour
- suivre le cadre d'établissement des indicateurs associés aux facteurs de stress décrit dans le présent document afin d'évaluer les risques auxquels est exposée la ZPM et de choisir les indicateurs pertinents à surveiller
- recueillir des données de référence en vue d'évaluer les changements naturels et les changements associés aux facteurs de stress
- élaborer un système exhaustif de déclaration pour évaluer la nature et l'étendue des activités humaines.

1 INTRODUCTION

Marine protected areas (MPAs) are designated by Fisheries and Oceans Canada (DFO) under the 1996 Ocean's Act to conserve biodiversity and protect the ecosystem function of a specific habitat or habitats. The establishment of an MPA is used as a management tool to complement or enhance existing tools used by managers to achieve DFO policies and legislation requirements for fishery and habitat management. Once an MPA is designated, the conservation objectives established for the MPA define the components of the ecosystem that are vulnerable to human activities and help define the indicators to monitor.

The goal of a monitoring plan is to assess the achievement of the conservation objectives. Science–based monitoring can be defined as the systematic collection of data and information on a regular basis for an extended period of time to determine the degree of achievement of some goal, standard or objective (Kenchington 2010). For both science and management purposes it is imperative that the conservation objectives are measurable, relevant to current policies, and sensitive to meaningful thresholds (Failing and Gregory 2003). To monitor MPAs effectively, the selection of indicators must be scientifically defensible, and provide information that is relevant to the conservation objectives of the MPA. A Stressor Based Indicator Identification Framework is intended to address only biological/ecological aspects of monitoring, and will focus on threat monitoring and monitoring trends in the ecosystem state through time. This information will be incorporated into a broader MPA management framework, which would also include socio-economic considerations. Other branches within DFO or other federal departments may be responsible for compliance monitoring, enforcement of regulations and developing the appropriate indicators for this work.

The need to monitor human activities within the hydrothermal vent community was identified in 2000 a workshop was held by members of the hydrothermal vent research community to discuss hydrothermal vent management (Dando and Juniper 2001). Many of the recommendations and outcomes from this workshop are included and will be discussed throughout this document.

This paper represents the first step in the development of indicators and monitoring protocols for the Endeavour Hydrothermal Vents MPA. The focus of this assessment was to:

- Develop a framework that will lead to indicator selection to allow for monitoring the effects of human activities that on achievement of the conservation objectives
- Conduct a preliminary Pathways of Effects (PoE) evaluation on the human activities that have the potential to stress the ecosystem and identify their likely effects; and,
- Describe current activity-based monitoring programs that may provide support to the development of a monitoring plan for the EHV MPA.

1.1 DESCRIPTION OF THE MARINE PROTECTED AREA

The EHV MPA is found at a depth of 2250m, approximately 250 km southwest of Vancouver Island (Figure 1). It is 100km^2 in size and is part of a larger network of vents and submarine volcanoes known as the Juan de Fuca Ridge located off the west coast of North America. Here the tectonic plates diverge and new oceanic crust is extruded. The vents are formed as cold sea water seeps down through the crust where it is heated by the underlying molten lava. The heated water is ejected through the seafloor as buoyant plume of particle-rich, superheated fluid at temperatures reaching 300°C. The mineral-rich plumes can rise up to 300m into the water column. Conditions within specific vent fields or at individual chimneys are characterized by different water temperatures, salt content, sulphide structure, and animal abundance. This rich ecosystem is supported by microbes whose life processes are fuelled by the chemical energy from the emerging fluids in the hydrothermal vents (Tunnicliffe and Thomson 1999). The

chemosynthetic bacteria grow in thick mats and provide a food source for invertebrate species (vestimentiferan worms, shrimp, bivalves, and others) that are in turn prey to a number of benthic predators (octopus, crabs, and fish). The vent fields support a high level of species richness compared to nearby ocean floor. At the time of designation at least sixty species were considered unique to hydrothermal vents and twelve endemic to the Endeavour vents (Tunnicliffe and Thomson 1999). Individual chimneys or larger vent complexes have been named and mapped by researchers, however because of the dynamic nature of the vent ecosystem chimneys can collapse without warning, thus changing the landscape of the vent field. Since its discovery in 1982, the Endeavour Hydrothermal Vents have been the focus of research by Canadian and international scientists studying many different aspects of the deep-sea ridge environment.

1.2 DESCRIPTION OF THE CONSERVATION OBJECTIVES

The gazetted Endeavour Hydrothermal Vents MPA conservation objective is to:

> *Ensure that human activities contribute to the conservation, protection and understanding of the natural diversity, productivity and dynamism of the ecosystem and are managed appropriately such that the impacts remain less significant than natural perturbations (e.g. magmatic, volcanic or seismic).*

The conservation objective for EVH MPA needs further refinement to address the scale of impact from human activities and the uncertainty regarding the scale of natural variation due to plate tectonics in the area. In order to ensure that this criterion is met, MPA managers must understand both the ecological footprint of any proposed human activity within the area, and the degree of natural disturbance that exists at hydrothermal vents. Operational objectives will need to be derived from the refinement of the broad conservation objective. These operational objectives will be essential to the development of a monitoring program that will measure ecosystem parameters that are useful and relevant for management of human-induced threats in the area.

The lack of clearly defined objectives inhibits the ability to identify and defend specific monitoring requirements without appearing to be an arbitrary selection. Measurable objectives are needed to: complete statistical tests on collected data; determine reference points for the selected indicators; and develop decision points for management actions. For indicators to support management decision making, the relationship between the value of the indicator and the operational objective needs to be understood (Jennings 2005).

1.3 DESCRIPTION OF MANAGEMENT OF THE MARINE PROTECTED AREA

There are five management areas that correspond to the main vent fields within the EHV MPA; Mothra, Main Endeavour, High-rise, Salty Dawg, and Sasquatch (Figure 2). The EHV MPA also contains the smaller vent fields that include Clam Bed and Quebec.

The management plan for EVH MPA (DFO 2010a) outlines the following management objectives that will be used to support decisions regarding human activities within the MPA:

1. Coordinate human activities to ensure responsible procedures are followed (e.g. sampling, instrument deployment and retrieval, data sharing, appropriate debris disposal).
2. Contribute to public awareness of the values of marine ecosystems and the need to protect them.

The management plan for EHV MPA also elaborates on the regulations to achieve the conservation objective for the MPA. It addresses matters such as monitoring, enforcement and compliance, and provides the details required to ensure that the rationale for management

decisions, prohibitions, controls and approvals is clearly understood. As stated by the regulations, activities in the MPA are managed through (1) specific exceptions to the general prohibitions according to specified conditions; and (2) the submission and approval of plans for specified activities according to specified conditions.

The regulations state that *'no person shall disturb, damage or destroy, or remove... any part of the seabed, including a venting structure, or any part of the subsoil, or any living marine organism or any part of its habitat; or carry out any underwater activity... that is likely to result in the disturbance, damage, destruction or removal of any part of the seabed, including a venting structure, or any part of the subsoil, or any living marine organism or any part of its habitat'* with the following exceptions.

- Activities for the purpose of public safety, law enforcement, Canadian sovereignty or national security, as well as activities undertaken on behalf of the Canadian Forces are allowed.
- Scientific research for the conservation, protection and understanding of the area may be approved throughout the MPA under specific conditions.
- Fishing by Aboriginal Peoples in accordance with the *Aboriginal Communal Fishing Licenses Regulations* is permitted.
- Commercial fishing within the MPA will be allowed as long as this is carried out in accordance with subsection 7(1) of the *Fisheries Act*.
- Vessel travel is permitted pursuant to the *Canada Shipping Act, 2001* and foreign vessel travel pursuant to the *Canada Shipping Act, 2001* and the *Coasting Trade Act*.

Although the regulations allow for activities that are necessary to ensure national security there currently are no Canadian Naval or Air Force activities that take place in the MPA. Fishing activity is infrequent and any licensed fishing takes place very near the ocean surface, so as not to significantly impact the hydrothermal vents ecosystem.

2 ASSESSMENT

2.1 STRESSOR BASED INDICATOR IDENTIFICATION FRAMEWORK

The framework for the identification of indicators to monitor the achievement of the conservation objective includes the following steps:

1. Use the Pathways of Effects (PoE) approach to identify the stressors that result from each activity and their potential effect on the ecosystem.
2. Conduct a risk assessment using an ecological risk analysis framework (ERAF) on the effects that have been identified though the PoE evaluation.
3. Refine conservation objective into measureable operational objectives.
4. Identify candidate indicators and protocols to monitor the effect of stressors from activities that have been assessed or prioritized, though the ERAF, to warrant monitoring (i.e. sufficient risk to achievement of the conservation objectives).
5. Identify candidate indicators and protocols to monitor the ecosystem reference state to serve as baselines for comparison to indicators relevant to stressors.

Pathways of effects (PoE) models or diagrams describe the type of cause-effect relationships that are known to exist, and the mechanism by which stressors ultimately lead to effects in the aquatic environment (DFO 2010b). For each human activity there are known stressors to the environment. Each of these stressors may have one or more effects on biodiversity (species, populations and communities), habitat or ecosystem form and function. This relationship can be described in the following schematic:

Activity → Stressor → Effect

For each cause-and-effect relationship, a pathway is created by connecting the attributes of the stressor to some ultimate effect on the ecosystem (Boutillier et al. 2010). For fishing activities, one of the pathways of effects that describe one of the effects from one stressor would be described by the following schematic:

Fishing → Removal of target species → Loss of biodiversity

In this example the activity is fishing, the stressor to the ecosystem is the removal of target species, and the potential effect could result in loss of biodiversity at the genetic, species and ecosystem level. This is only one of several pathways for this activity and is not a complete assessment of all the stressors nor all potential effects. Each pathway represents an area where mitigation measures can be applied to reduce or eliminate a potential effect (DFO 2010b). Where mitigation measures cannot be applied, or cannot fully address a stressor, the remaining effect is referred to as a residual effect (Boutillier et al. 2010). Figure 3 illustrates an example of a pathway of effect that has been developed by DFO to communicate potential effects of marine seismic activities on fish and fish habitat.

Once the pathways of effects have been outlined an ecological risk assessment of human activities is needed to determine the level of risk that residual effects pose to the ecosystem. This type of assessment will categorize risks to the ecosystem by examining the scale and intensity of negative effects associated with human activities and the sensitivity of biodiversity, habitat and ecosystem form and function within the MPA. An understanding of the risks is necessary to select indicators for monitoring.

Indicators can be grouped into one of two categories; those that monitor the impact of human activities, and those that monitor the ecosystem reference state. For the EHV MPA the selection of appropriate and meaningful indicators is not possible until the conservation objective is refined into measurable terms, or operational objectives. The outputs from the pathways of effects and ecological risk assessment processes will help inform and refine the conservation objectives for the area. Specific operational objectives that are measurable and describe conservation priorities will need to be defined before potential indicators can be proposed.

2.2 IDENTIFICATION OF POTENTIAL STRESSORS

The stressors and their effects caused by human activities that take place within the MPA may compromise the achievement of the conservation objective and the more specific operational objectives. Key activities that may impact the MPA were identified in an Oceans background report (Tunnicliffe and Thomson 1999) and the 2000 a workshop (Dando and Juniper 2001). The effects on biodiversity, habitat and ecosystem form and function from these activities (vessel traffic, tourism, scientific research) and the present management protocols used to mitigate the stressors from these activities are described below. N.B. Oil and mineral exploration or extraction where not included as activities in this exercise because the regulations for the MPA prohibit these activities in this area.

This section will outline the PoEs but does not assess the likelihood of negative effects, frequency of activities or priority for monitoring. It is important to note that not all effects from human activities are negative, and that further assessments by experts may be necessary to characterize the level of risk to the biodiversity, habitat and ecosystem form and function from each of the activities described.

Due to the remote location of the EHV MPA it is not subjected to many of the potential threats found near populated regions. Before the discovery of the vents few human activities took place in the area. Fishing for tuna and neon squid occurs periodically within the water column, but these activities do not impact the seafloor ecosystem and are therefore not considered a threat. Other hydrothermal vent sites around the world have been identified as potential sites for deep-sea mining and bioprospecting (extracting enzymes from hydrothermal bacteria). However, the regulations for EHV MPA explicitly state that removal of any part of the subsoil or any living marine organism is prohibited, with the exception of scientific research and eliminates the potential for deep-sea mining activities within the MPA.

Since the discovery of the vent system along the Juan de Fuca Ridge various groups have expressed interest in studying the area for scientific research and using the vents as a tourism venue. Each of these activities has the potential to impact the vent ecosystem.

2.2.1. Vessel Traffic

There likely exists a small amount of vessel traffic in the area from research activities and potential fishing activities. However, due to the remote location of this MPA the amount of traffic is unknown. The potential risks to the area include oil spills which can cause a loss of biodiversity, alter habitat and the reproductive potential of populations. The unintentional transport of aquatic invasive species from ballast water and the establishment of an exotic species can also cause a loss of biodiversity, reduce available habitat and alter ecosystem function. Vessel strikes on marine mammals can cause the removal of individuals from a population. The potential pathways of effects from vessel traffic are outlined in Table 1.

Table 1. Pathways of effects for vessel traffic

Activity	Stressor	Effect
Vessel Traffic	Oil spill	Loss of biodiversity
		Alteration of habitat
		Alteration of reproductive & developmental potential of populations
	Exotic species introduction (from ballast water)	Reduction of available habitat
		Loss of biodiversity
		Alter ecosystem function
	Vessel strikes	Removal of individuals (marine mammals)

2.2.1. Scientific Research and Monitoring

Scientific research is the only activity that currently takes place along the seafloor within the MPA boundary. Most scientific research in the area has focused on the geology of the area and geophysical processes of the vent system. Less work has been completed on the biology of the animals found at the vents and the hydrothermal vent ecosystem. Researchers are interested in the site for the purpose of public awareness and education, furthering the understanding of deep ocean community structure and function, and as a natural laboratory to study ore-forming processes. Data collection methods have included measurements of the physical and chemical characteristics along the seabed, deploying time-series observation equipment, collection of sediment and biota samples, seismic and acoustical sampling, and capturing video footage from either submersible vehicles or fixed station cameras.

Each of theses activities can cause damage to the flora and fauna of the hydrothermal vent community and may cause a behavioural response in the animals to foreign elements and light. The potential pathways of effects from scientific research are outlined in Table 2. Sediment or chimney structures may be disrupted from accidental contact by submersible vehicles or by the use of their thrusters. Foreign materials used in permanent or temporary structures may introduce exotic microbes to the area. If left on the sea floor permanently these structures may alter habitat. Seismic activities may impact marine mammals, turtles, fish, and invertebrates that are present both along the seafloor and in the water column. These impacts will vary from species to species and according to the proximity and characteristics of the sound source arrays (DFO 2004). Potential short term impacts of sample collection (sediment, biological specimens, vent structure, or vent fluid) could include disruption of community structure, loss of biodiversity and changes in complex habitat. Trophic effects from the reduction of populations (predator &/or prey) may cascade through the ecosystem. This is compounded by the relatively small areas that animals tend to occupy on the surfaces of and below the surface of the venting structures, where the biomass may range up to half a million animals per square metre of vent surface (Glowka 2003). Future concentration of activities at certain sites could produce local and even regional effects on biological processes and organism abundance to the point where the scientific value of the site could be compromised and, eventually, the survival of some species could become an issue (Dando and Juniper 2001).

The stressors due to vessel traffic associated with scientific research are described above vessel traffic section (2.2.1).

Table 2. Pathways of effects for scientific research and monitoring activities

Activity	Stressor	Effect
Scientific research & monitoring	Light	Harassment of species (benthic)
	"Unintentional" habitat damage (collisions)	Loss of habitat
		Indirect effects on biodiversity from the destruction of habitat and biogenic species that create complex habitat
	Exotic species introduction (from equipment)	Reduced available habitat
		Loss of biodiversity
		Alter ecosystem function
	Debris and permanent structures	Alteration of habitat
	Sound energy introduction (noise)	Harassment of species (marine mammals)
	Sample collection (water, sediment, biota)	Loss of biodiversity
		Changes in complex habitat
		Trophic effect from the reduction of populations (predator &/or prey) that cascade through the ecosystem

2.2.1. Tourism

Members of the general public have an interest in experiencing the natural beauty and high biodiversity of the unique hydrothermal vent ecosystem. Although tourism interest at EHV MPA is extremely limited, tourism operators have expressed interest in conducting submarine tours to the area. Impacts from submarine activities would be similar to those from submersible research vehicles described above; sediment or chimney structures may be disrupted from contact by the vehicle or by the use of their thrusters. However, the high cost of such an operation, remote location and poor weather conditions in the area limit the tourism potential at this time. The potential pathways of effects for tourism are outlined in Table 3. The stressors due to vessel traffic associated with tourism are described above vessel traffic section (2.2.1).

Table 3. Pathways of effects for tourism activities

Activity	Stressor	Effect
Tourism	Light	Harassment of species (benthic)
	Physical disturbance	Harassment of species (benthic)
		Alteration of habitat

2.3 ECOLOGICAL RISK ANALYSIS

Completing the pathways of effects analysis for all the human activities that take place within the MPA will identify effects that need to be evaluated using an ecological risk analysis

framework (ERAF). The ERAF is a starting point to ask scientifically plausible questions about the nature and extent of the effects of human activities. Many different types of ecological risk analysis frameworks exist to address different ecosystems and human activities. DFO has developed an ecological risk analysis framework for habitat assessment that can be used to understand the impacts of activities within an MPA. This risk analysis framework is intended to provide a structured approach to decision-making that takes into account the concepts of risk, uncertainty and precaution (DFO 2010b).

To assess risk from a specific stressor, the scale of negative effects as identified in the PoE, must be considered in context with the sensitivity of the biodiversity habitat, or ecosystem form or function that is being impacted. The scale of negative effect can be described as the extent or direct or indirect footprint of the stressor, the duration or amount of time that effects from the stressor will persist in the environment, and intensity of the stressor. The sensitivity of the ecosystem components (biodiversity, habitat or ecosystem form or function) can be described as the expected degree of change due to the stressor and ability of the ecosystem component to recover. The risk assessment matrix (Figure 4) incorporates these two factors in order to characterize the residual effects as either low risk, medium risk, high risk and significant negative effects (DFO 2010b). The residual effects are those effects to the ecosystem that can not be mitigated. The rationale used to locate the residual effects on the matrix forms the basis for decision-making (Boutillier et al. 2010). The risk assessment matrix can also be used to acknowledge uncertainty associated with predicting the scale of negative effects on the ecosystem. Uncertainty can be represented visually on the risk assessment matrix by plotting a circle or oval of various sizing around the point plotted; a small circle would represent a low level of uncertainty whereas a large circle would represent a high level of uncertainty (Figure 5). An oval can be plotted in situations where there is a high level of uncertainty for one descriptor and a low level of uncertainty for other descriptors.

Completion of both the pathways of effects and a risk assessment will produce a large volume of information to describe the stressors and effects for each activity. Plotting the results on a risk assessment matrix may not provide enough direction to prioritize a monitoring plan. It may be necessary to determine the frequency or likelihood of occurrence for each activity, and their associated effects, in order to judge the severity of impact and prioritize monitoring efforts. An activity with a high level of risk but a low probability of occurrence should not necessarily be given the same priority as an activity with a low or medium level of risk but a high probability of occurrence. It is also important to consider cumulative effects due to similar stressors from several different activities when ranking the severity of effects. There may be synergistic effects whereby two or more effects in combination express a greater impact than the sum of the individual impacts.

2.4 REFINEMENT OF CONSERVATION OBJECTIVES

If conservation objectives established for a particular MPA are not measurable, then the identification of the stressors, their effects and the resulting risk they pose may help inform the development of measurable objectives. Conservation objectives, thus redefined, are often referred as operational objectives. Conservation objectives should use language that directly corresponds to the language in policies, regulations, and legislation that already exists (DFO 2007a).

The need for clear and specific operational objectives is supported by a rich body of scientific literature on the selection of indicators and development of monitoring protocols (Noss 1999; Dale and Beyeler 2001; Failing and Gregory 2003; Niemi and McDonald 2004; DFO 2008; Niemeijer and de Groot 2008). When developing a cost-effective, statistically sound, and scientifically defensible monitoring program, all decisions related to indicator selection, sampling design and optimal allocation of research dollars should be informed by specific operational

objectives. Ultimately, the lack of clearly specified objectives can lead to inconsistent and scientifically indefensible management actions, the inability to assess management success (Failing and Gregory 2003).

The current conservation objective for the EVH MPA, *'to ensure impacts from human activities remain less significant than natural perturbations'* acknowledges that natural variation in the area due to plate tectonics can be catastrophic. However this objective can have no measurable meaning until both the impacts of human activities are accurately documented and the amount of human impact that is acceptable is be more clearly defined. It will also be necessary to define the desired target state, along with a timeframe and an acceptable probability of achieving the state (assuming the current state does not meet the targeted state). For EHV this poses a difficult challenge due to the amount of seismic and volcanic activity associated with the hydrothermal vents and dynamic state of the ecosystem. The involvement of other branches within DFO (Fisheries and Aquaculture Management, Science, etc.) will be essential to ensure operational objectives have a mechanism to support decisions regarding the human activities within the MPA.

Given that the high level conservation objective has not been unpacked into operational objectives, the authors' ability to provide scientifically defensible advice on key indicators and monitoring protocols is severely limited. However, in the absence of the anticipated operational objectives, work can begin on steps 1 and 2 of the five step Stressor Based Indicator Identification Framework described in section 3.1. Completion of the pathways of effects and risk assessments will provide information that can assist in the refinement of the conservation objectives into operational objectives.

3 MONITORING ACTIVITIES

3.1 CURRENT STATE OF MONITORING ACTIVITIES

Several different types of monitoring are needed for a Marine Protected Area monitoring program. Activity monitoring can be used to determine the nature and extent of impact from human activities in the area. Compliance monitoring can ensure that regulations and legislation around human activities are being followed. Trend monitoring can be used to track changes in the ecosystem through time, and effectiveness monitoring can evaluate ability of management actions to meet conservation objective.

In 2000 a workshop was held by members of the international hydrothermal vent research community to discuss hydrothermal vent management (Dando and Juniper 2001). This workshop recommended an environmental impact assessment be completed to determine the ecological footprint of proposed research activities within a vent field. Only then will it be possible to make management decisions based on estimates of disturbance (fraction of individual types of habitat that would remain undisturbed, and total disturbance) (Dando and Juniper 2001). This advice supports the steps outlined in the Stressor Based Indicator Identification Framework in this document to complete an ecological risk assessment of the stressors and their effects that result from human activities within the MPA.

Currently most of the work completed at the hydrothermal vents has focused on understanding the geological setting, fluid flow and water chemistry. Much of the peer-reviewed work is devoted to vent water characters, regional setting, mapping techniques, and geophysical controls of hydrothermal vents. A few studies have described the fauna of the vent ecosystem, both micro and macroscopic, their life processes and interrelationships. Collected data have focused on the geophysical, geochemical, volcanology, and structural geology aspects of the area with only a small amount of work by investigators on the water column character, water

physics, and plume dynamics. Even less work has been completed on identifying and cataloguing species found at vent sites and understanding ecosystem structure.

Knowledge gaps exist in all of the above areas as scientists are only beginning to understand the geological, physical, and chemical processes that drive hydrothermal vent activity at sites around the globe. Baseline work is needed to quantify the species richness of the area and describe new taxa. There is also a limited understanding of community structure and recruitment processes in the constantly changing vent ecosystem where habitable conditions can change rapidly.

Access to the area is regulated by DFO to ensure that activities are coordinated. Researchers must submit proposed research plans to the Technical Advisory Committee (TAC), which is comprised of members from government agencies, academic researchers, and environmental groups. The TAC evaluates the proposed research plans using the Draft Research Activity Review Framework and determines if the potential impacts from proposed studies are acceptable. This framework lays out a decision tree to identify situations where disturbance, damage, destruction and removal may be approved under the regulations, as well as situations where it would not be acceptable (Canessa et al. 2005). The management plan outlines specific activities that can be focused within particular management areas (Table 4). This is to ensure that researchers do not interfere with other studies and concentrates activities with similar impacts to one area. The EHV MPA regulations outline the type of information that can be requested from researchers in order to document use of the area. However, the MPA regulations do not restrict research activities to the management areas, and hence, all research activities can take place throughout the MPA; nor do the regulations restrict the type of activities that can take place within the MPA.

Table 4. Activities supported within Endeavour Hydrothermal Vents Management Areas

Research Activity	Management Area				
	Main Endeavour	Mothra	High Rise	Salty Dawg	Sasquatch
Observation based studies	√	√	√	√	Management aims will be identified by 2012
Water sampling				√	
Acoustic Imaging				√	
Water column investigations				√	
Public education/outreach			√		
Moderate sampling/collection	√	√			

In the interest of preserving deep-sea hydrothermal vents for scientific use, a code of conduct for sustainable use of deep-sea vent systems has been developed by InterRidge and the international research community (Appendix 1). Currently 88 researchers from 18 different countries have signed the voluntary, non-binding statement of conduct (InterRidge 2010). The code of conduct represents guidelines that individual researchers have agreed to adhere to, and is not a binding international commitment made by member nations.

In addition to authorizing access, DFO participates in several programs that track the status of oceanographic conditions in the North Pacific. These include the free-drifting profiling floats for the Argo project that provide information on water temperature and salinity profiles and as well as satellite imagery from SeaWiFS and MODIS satellites that monitoring phytoplankton and nitrate levels. However, the hydrothermal vents are located 2250 meters below the ocean surface and are influenced by volcanic and plate tectonic activity below the seafloor (Macdonald et al. 2001). Oceanographic conditions at the sea surface for the area will not provide MPA managers with the information necessary to determine if conservation objectives are being achieved. Monitoring of plate tectonic activity along the Juan de Fuca Ridge is currently being undertaken by researchers from Neptune Canada at several observation stations along the ocean floor at EHV MPA. This work will monitor spatial and temporal variability associated with seafloor spreading (Neptune Canada 2010).

3.2 SELECTION OF APPROPRIATE AND MEANINGFUL INDICATORS AS RELATED TO CONSERVATION OBJECTIVES

The selection of indicators for EHV MPA is not possible until the operational objectives are developed. Indicators for a science monitoring program should inform and support decision-making necessary for the management of an Ocean's Act MPA. To meet this need the indicators should be used to answer the basic questions; Are the conservation objective being met? This question should be expanded to a set of scientifically based questions and testable hypotheses that relate to the specific conservation objectives for the MPA, and the human activities that impact the MPA ecosystem.

The selection of indicators for any MPA will depend on the nature of the conservation objectives. Some MPAs have straight-forward conservation objectives that relate to a specific species or habitat function, for example the protection of the Gilbert Bay cod population and its habitat (DFO 2010d). These MPAs may be well suited to relatively simple and easily defined indicators and the straightforward wording of the conservation objective may actually articulate the indicator. Other MPAs, such as EHV MPA have broader conservation objectives that describe the maintenance of productivity of an ecosystem and are better suited to indicators that monitor complex systems or ecosystem-level characteristics. Broader conservation objectives will provide a challenge when determining indicators that provide meaningful data if the conservation objectives are so broad that they describe aspirations rather than specific operational objectives. Unpacking the broad conservation objectives into finer scale conservation objectives based on stressor based framework which; identifies the human activities that can be managed; understands the stressors associated with the activity; and quantify resulting effects against which that take place within the MPA will provide the most relevant information to MPA managers and allow for the sustainable management of these activities and the conservation of biodiversity, habitat and ecosystem form and function. Ideally the suite of indicators should represent key information about structure, function, and composition of the ecological systems (Dale and Beyeler 2001), and should be linked in a logical manner to the conservation objectives. Indicators that cannot be linked to a specific operational objective should not be proposed for inclusion in a monitoring program. By the same token, all operational objectives should be linked to at least one key indicator so that progress on meeting all operational objectives can be evaluated.

If indicators are to be used in a structured decision support context, their selection must be guided even more closely by suitable criteria (Rice and Rochet 2005). These criteria will assess the quality of the information provided by a candidate indicator. Rice and Rochet (2005) have proposed the following set of nine criteria for evaluating candidate indicators; concreteness, theoretical basis, public awareness, cost, measurement, historic data, sensitivity, responsiveness, and specificity. It is essential that the indicators selected describe a concrete

property of the ecosystem that can be measured (either directly or in-directly). The candidate indicators should also be sensitive and responsive to change, and have specificity to a particular management action. Other criteria to consider in the screening process include the existence of historical data, public awareness, and theoretical basis for use of the particular indicator. Cost is also a consideration when prioritizing indicators for monitoring.

3.3 PROTOCOLS FOR MONITORING / APPROACHES AND WORKPLANS

A methodology to understand the ecological footprint of each human activity is described below and a workplan for specific data requirements and analysis are summarized. In some instances protocols for data collection and historical data sets may already exist for some indicators; in other cases protocols may need to be developed and baseline surveys completed. Some of this work will require additional data collection, including vessel time and staff to complete the field studies, and subsequent data analysis. Operational objectives and monitoring priorities will be necessary to prioritize this work. Data management will need to be incorporated into all workplans.

3.3.1. Monitoring Scientific Research

Monitoring Activity Impacts

DFO has developed a Risk Management Framework for Habitat Management (DFO 2010c) that includes a risk assessment based on the scale of negative effect, sensitivity of habitat, and categorization of risk. This framework describes the management of risk as dependent on the scale of the negative effect (high, medium, or low). The 2000 InterRidge workshop (Dando and Juniper 2001) also discussed risk assessment and provided recommendations specific to hydrothermal vents. This includes the characterization of the type of disturbance that is associated with specific research activities, estimation of the percent loss of seafloor, and identification of potentially affected seafloor organisms.

An impact assessment can inform the Technical Advisory Committee of the ecological footprint of proposed research activities. Only then will it be possible to make management decisions based on estimates of disturbance (fraction of individual types of habitat that would remain undisturbed, and total disturbance) (Dando and Juniper 2001). Impact assessments should follow the Risk Management Framework and incorporate recommendations from the 2000 InterRidge workshop.

Compliance monitoring of research activities will also be necessary to determine general trends regarding human use of the area. This includes adhering to existing mitigation requirements such the Statement of Canadian Practice with respect to the Mitigations of Seismic Sound in the Marine Environment (DFO 2007b). Currently, researchers are required to submit a post-cruise logbook as a condition of access to the MPA.

Table 5. Workplan for monitoring activity impacts

Work needed	Potential existing datasets and protocols
Determine the nature and extent of scientific research within the MPA	Review previous post-cruise logbook data and proposed research activities to determine ecological footprint of activities

Assessment of Wildlife and Habitat

An ecosystem conservation strategy is required to ensure the unique biodiversity of the hydrothermal vents persists through time. This approach has been used in other unique ecosystems within Canada such as the Garry oak forest and Southern interior grasslands of British Columbia where COSEWIC has identified a number of species that are at risk due to habitat restrictions.

Collection of the necessary baseline data on species composition and distribution throughout the MPA may not be feasible due to logistical challenges of working in the area and limited taxonomic knowledge of species encountered. However all observations should be documented to provide information for COSEWIC species status assessments. This information should include the species (or lowest possible taxonomic level), location coordinates and an estimate of the number of individuals present. Appendix 2 provides the criteria that species distribution data will be evaluated against when assessing stock status by a COSEWIC technical subcommittee. Most species that are unique to the hydrothermal vent communities would be eligible for species at risk status according to these criteria.

Table 6. Workplan for assessment of wildlife and habitat

Work needed	Potential existing datasets and protocols
Determine the species richness of the Endeavour Hydrothermal Vents	Review previous post-cruise logbook data and publications to develop species lists

4 DISCUSSION

Ultimately DFO is responsible for the coordination of science monitoring in the MPA. However, a collaborative effort involving a variety of organizations and research groups will be necessary to successfully monitor this remote seamount. Collaboration may need to include other DFO branches (i.e. Fisheries and Aquaculture Management, Oceans and Habitat Enhancement, Science, Conservation and Protection etc.) and other federal departments (Environment Canada and Transport Canada) as well as external partners (academic researchers), in order to share resources and achieve similar goals.

Planning for long-term monitoring activities will be crucial for the development of a long-term data set and the ultimate success of a monitoring program. Data gathered may require vessels or aircrafts of opportunity, fixed station monitoring, or remote sensing. When possible, data collection should be coordinated to support multiple objectives.

Research and monitoring activities at this MPA are only feasible from large vessels or from expensive remote observation nodes such as NEPTUNE Canada's cabled observatory. For this reason, potential researchers are likely to be limited to government agencies or university scientists. Opportunities for monitoring activities to be completed by external (non-government) researchers will be dependent on external funding sources and research interest in the area. Scientific funding in the US, particularly by the National Science Foundation, is extremely competitive (DFO 1999). Linkages with other researchers through existing networks such as Ridge2000 or InterRidge may provide a venue for tracking research activities and data sharing. Ridge2000 is a multidisciplinary science research program funded by the National Science Foundation that focuses on the Juan de Fuca Ridge. Ridge2000 also assimilates data from research cruises into a web-accessible repository for the scientific community (see http://www.ridge2000.org/science/iss/endeavour/). Unfortunately the repository contains only

information on Ridge2000 research that is funded by the National Science Foundation and is therefore an incomplete summary of research activities at EHV MPA. InterRidge facilitates research on deep sea vent ecology worldwide by building consensus on important policy issues regarding vents around the globe such as developing a code of conduct for deep-sea vent researchers and maintaining a database of global deep sea vent fields. The above mentioned research groups may provide opportunities to address knowledge gaps related to understanding the natural variability of the area.

To determine the nature and effects that human activities have on the achievement of the broader conservation objective, a comprehensive reporting system is required that captures existing and proposed activities at EHV MPA. Currently, reporting of activities in the area takes place through cruise logbooks. Development of a data management system is an integral component to a monitoring program, as it will ensure data integrity and access. Data management will be necessary to compile historic information, information gathered for completing risk assessments, as well as current and future monitoring activities.

Several knowledge gaps exist that will need to be addressed in order to develop a monitoring program. There are information gaps regarding the frequency of human activities in the MPA, as well as uncertainties regarding the nature and extent of the stressors and their effects that result from these activities. The ability to complete the steps in the Stressor Based Indicator Identification Framework, including the refinement of the conservation objective, will be dependent on the data available. Knowledge gaps also include a detailed understanding of the species composition, colonization and succession processes of the vent ecosystem. This statement could be made for deep sea vent systems throughout the world. To date there is not a single site for which the entire meiofauna community structure is known (Desbruyères et al. 2006).

There are sources of uncertainty regarding the ecosystem structure and function that will continue to exist, regardless of how extensive and thorough a monitoring program becomes. Cumulative impacts also need to be acknowledged when assessing the effects of human activities, developing management measures and prioritizing monitoring efforts. These are difficult to identify and hence have the potential of being overlooked or underestimated.

Although the conservation objective for the EHV MPA is to ensure impacts from human activities remain less significant than natural perturbations, the nature and extent of both human activities and natural variation is unknown. Without understanding the human use and natural variation of the area, it will be difficult to assess the achievement of the high level conservation objective, and to understand the ecosystems resilience to stressors.

5 CONCLUSIONS AND RECOMMENDATIONS

The identification of appropriate indicators to assess whether a MPA is achieving the established conservation objectives is a key component of overall management planning and implementation. The identification of indicators that are relevant and prioritized can only be successfully achieved when objectives are measurable, and for the EHV MPA, this is currently hampered by the lack of specific operational objectives.

In the absence of operational objectives, it is important to direct monitoring efforts to an evaluation of human activities in the MPA. This document proposes a five-step framework for the identification of indicators that is based on an evaluation of activities, and identifies the human activities that would be considered human induced ecosystem stressors which would have effects on the ecosystem components of the broad conservation objective including biodiversity, habitat and ecosystem form and function. A preliminary PoE assessment was conducted for human activities currently occurring at EHV MPA, to identify stressors and effects that impact on ecosystem components above. A more thorough evaluation of the stressors to

this MPA needs to be completed before a risk assessment can be undertaken. Once the risk assessment is complete it will provide guidance priorities for the development of measurable conservation objectives. Once these operational conservation objectives are set then it will be easier to set potential indicators that include the criteria: concreteness, theoretical basis, public awareness, cost, measurement, historic data, sensitivity, responsiveness, and specificity measurable to the conservation objectives. Effective monitoring of an MPA will also require an understanding of the ecosystem processes and natural variability that take place within the MPA.

Recommendations:

1. Follow prescribed Stressor Based Indicator Identification Framework as described in this document to assess risks to the MPA and select appropriate indicators for monitoring.
2. Collect and compile data to develop a knowledge base of rare and endemic species (or lowest possible taxon).
3. To determine the nature and effects that human activities have on the achievement of the broader conservation objective, a comprehensive reporting system is required that captures existing and proposed activities at EHV MPA.

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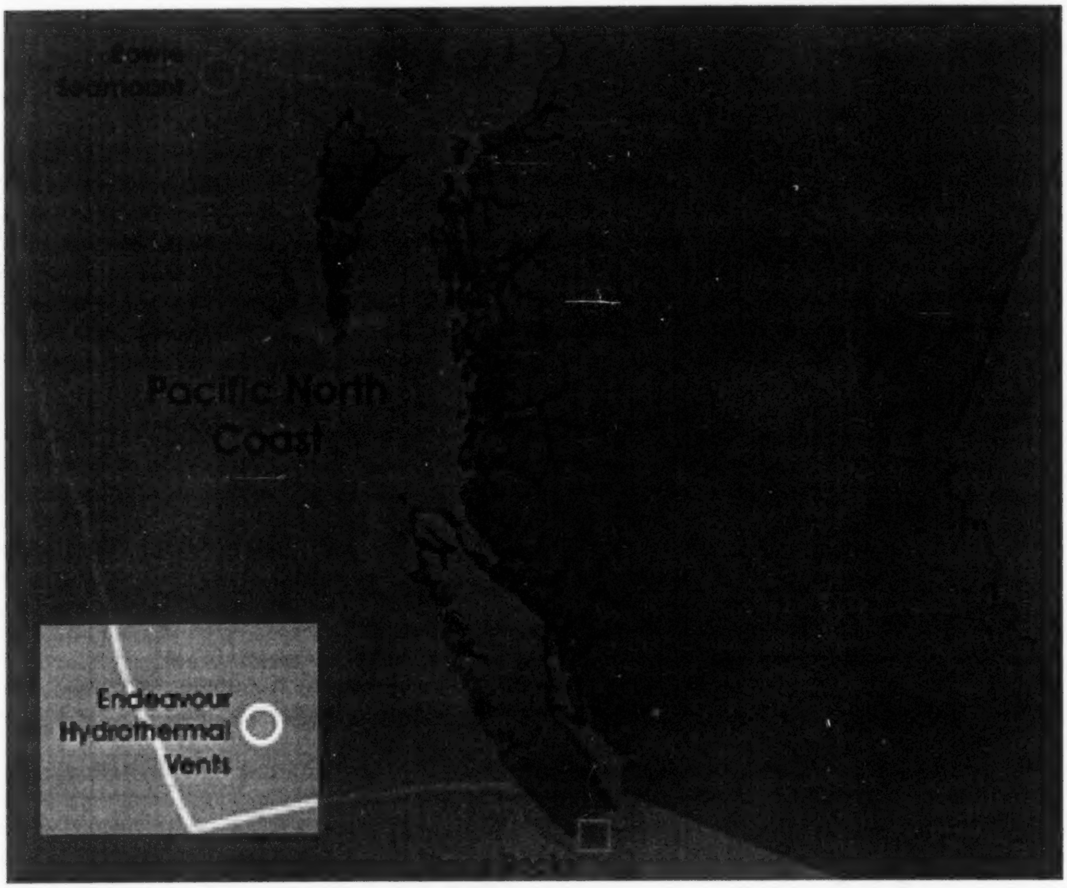

Figure 1. Endeavour Hydrothermal Vents location map

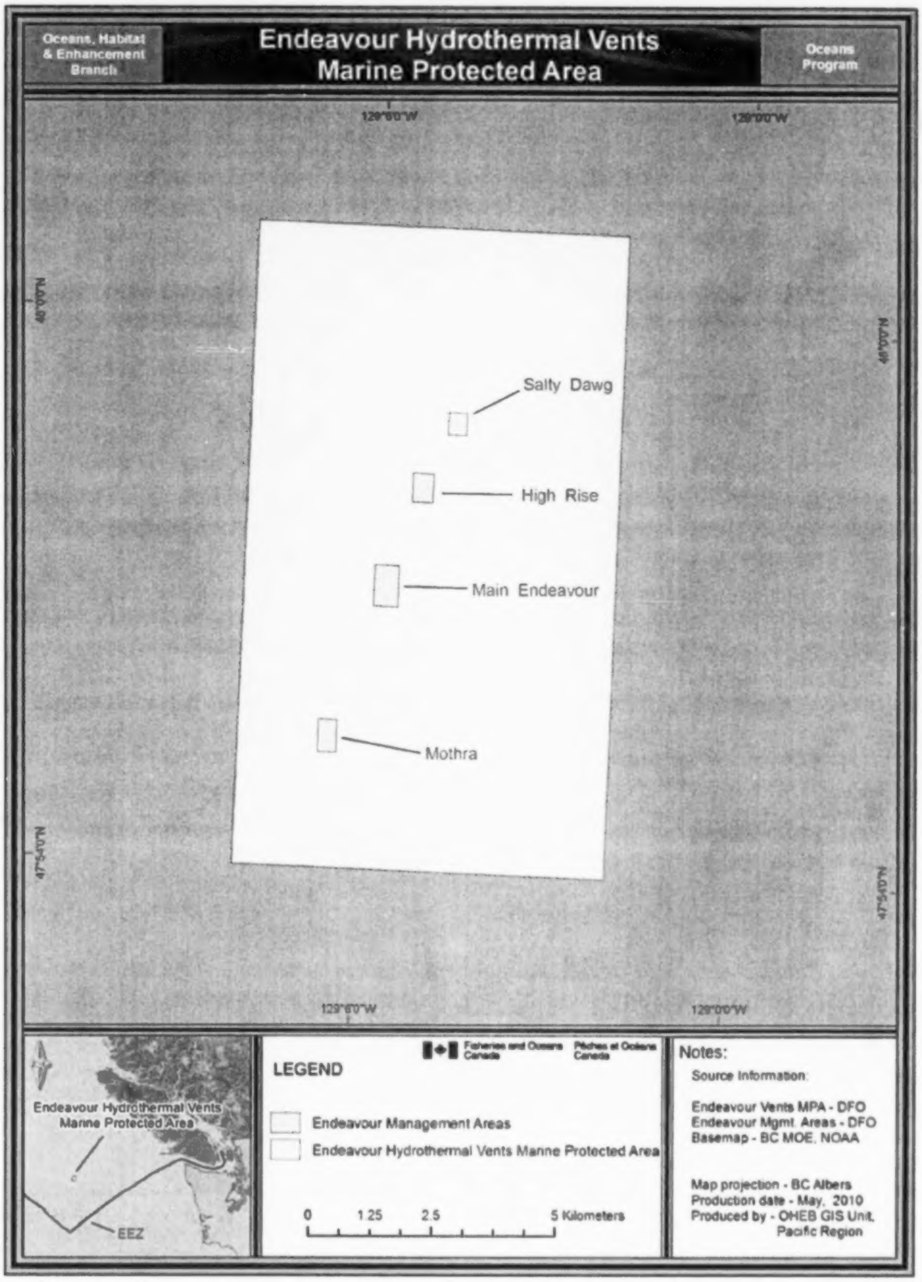

Figure 2. Endeavour Hydrothermal Vents Management Areas

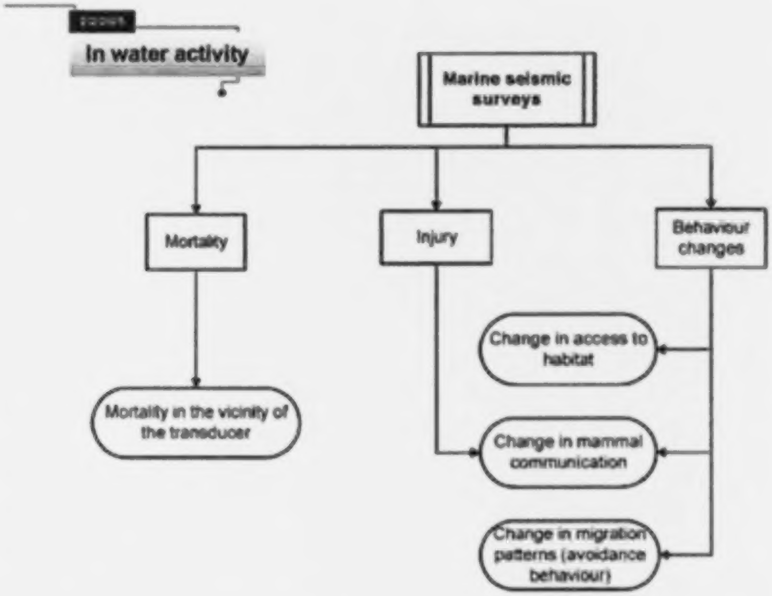

Figure 3. Pathways of effects for marine seismic surveys

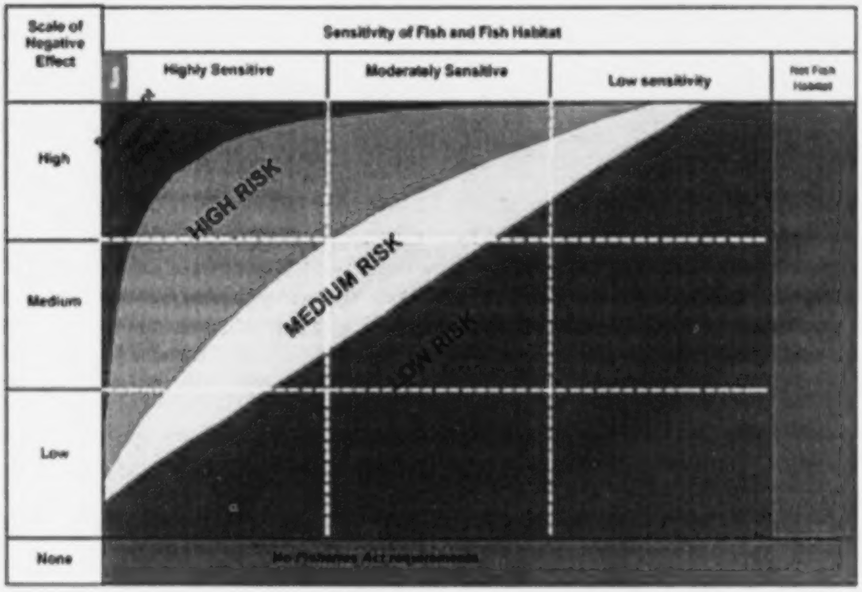

Figure 4. Risk Assessment Matrix Used to Illustrate Various Categories of Risk (DFO 2010c)

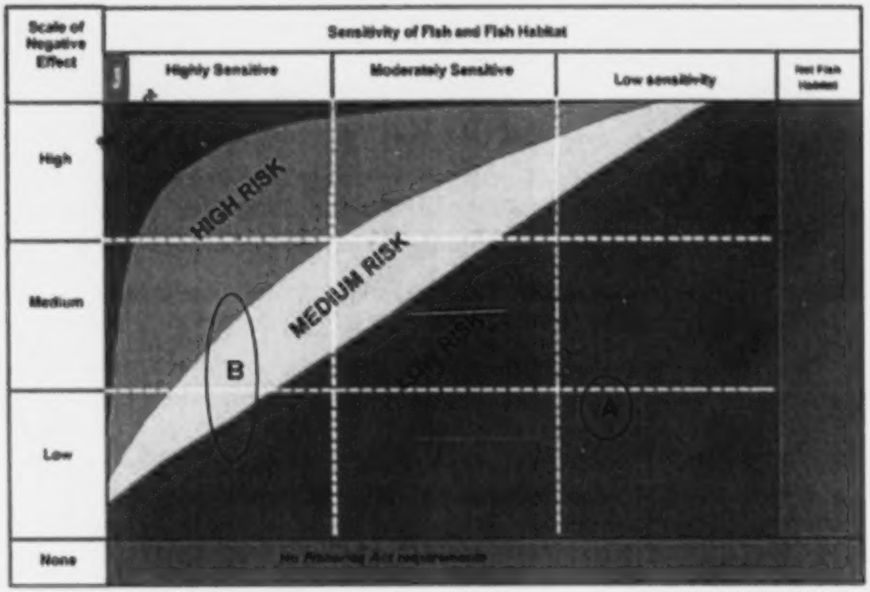

Figure 5. Risk assessment matrix used to illustrate uncertainty. (A) Low risk project with little uncertainty associated with the risk assessment. (B) A high degree of uncertainty associated with predicting scale of negative effect has led to an overlap of risk categories (DFO 2010c)

APPENDIX 1. INTERRIDGE STATEMENT OF COMMITMENT TO RESPONSIBLE RESEARCH PRACTICES AT DEEP-SEA HYDROTHERMAL VENTS

1. Avoid, in the conduct of scientific research, activities that will have deleterious impacts on the sustainability of populations of hydrothermal vent organisms.
2. Avoid, in the conduct of scientific research, activities that lead to long lasting and significant alteration and/or visual degradation of vent sites.
3. Avoid collections that are not essential to the conduct of scientific research.
4. Avoid, in the conduct of scientific research, transplanting biota or geological material between sites.
5. Familiarize yourself with the status of current and planned research in an area and avoid activities that will compromise experiments or observations of other researchers. Assure that your own research activities and plans are known to the rest of the international research community through InterRidge and other public domain data bases
6. Facilitate the fullest possible use of all biological, chemical and geological samples collected through collaborations and cooperation amongst the global community of scientists.

APPENDIX 2. COSEWIC QUANTITATIVE CRITERIA AND GUIDELINES FOR THE STATUS ASSESSMENT OF WILDLIFE SPECIES

Indicator	Endangered	Threatened
A. Declining Total Population		
A1. An observed, estimated, inferred or suspected reduction in total number of mature individuals over the last 10 years or 3 generations, whichever is the longer, where the causes of the reduction are: clearly reversible **and** understood **and** ceased, based on (and specifying) any of the following: (a) direct observation (b) an index of abundance appropriate to the taxon (c) a decline in index of area of occupancy, extent of occurrence and/or quality of habitat (d) actual or potential levels of exploitation (e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites	Reduction of >70 %	Reduction of >50 %
A2. An observed, estimated, inferred or suspected reduction in total number of mature individuals over the last 10 years or 3 generations, whichever is the longer, where the reduction or its causes may not have ceased **or** may not be understood **or** may not be reversible, based on (and specifying) any of (a) to (e) under A1.	Reduction of ≥ 50%	Reduction of ≥ 30%
A3. A reduction in total number of mature individuals, projected or suspected to be met within the next 10 years or 3 generations, whichever is the longer (up to a maximum of 100 years), based on (and specifying) any of (b) to (e) under A1.	Reduction of ≥ 50%	Reduction of ≥ 30%
A4. An observed, estimated, inferred, projected or suspected reduction in total number of mature individuals over any 10 year or 3 generation period, whichever is longer (up to a maximum of 100 years in the future), where the time period must include both the past and the future, and where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on (and specifying) any of (a) to (e) under A1.	Reduction of ≥ 50%	Reduction of ≥ 30%
B. Small Distribution Range and Decline or Fluctuation		
B1. Extent of occurrence estimated to be **or**	< 5,000 km²	< 20,000 km²
B2. Index of area of occupancy estimated to be **and** (for either B1 or B2) estimates indicating at least two of a–c:	< 500 km²	< 2,000 km²
a. Severely fragmented **or** known to exist at:	≤ 5 locations	≤ 10 locations
b. Continuing decline, observed, inferred or projected, in any of (i) extent of occurrence, (ii) index of area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or populations, (v) number of mature individuals.		
c. Extreme fluctuations in any of (i) extent of occurrence, (ii) index of area of occupancy, (iii) number of locations or populations, (iv) number of mature individuals.		
C. Small and Declining Number of Mature Individuals		
C. Total number of mature individuals estimated to be:	<2,500	<10,000

and one of either C1 or C2: C1. An estimated continuing decline in total number of mature individuals of at least:	20% within 5 years or two generations, whichever is longer, up to a maximum of 100 years in the future	10% within 10 years or three generations, whichever is longer, up to a maximum of 100 years in the future
or C2. A continuing decline, observed, projected, or inferred, in numbers of mature individuals **and** a.(i) No population estimated to contain	> 250 mature individuals	> 1000 mature individuals
or a.(ii) one population has	≥ 95% of all mature individuals	100% of all mature individuals
or b. There are extreme fluctuations in number of mature individuals.		
D. Very Small or Restricted Total Population D. Total number of mature individuals very small or restricted in the form of either of the following:		
D1. Population estimated to have	< 250 mature individuals	< 1000 mature individuals
or D2. **For threatened only**: Population with a very restricted index of area of occupancy (typically < 20 km²) or number of locations (typically ≤ 5) such that it is prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and is thus capable of becoming endangered or extinct in a very short time period.	Does not apply	Index of area of occupancy < 20 km² **or** ≤ 5 locations
E. Quantitative Analysis		
E. Quantitative analysis (population projections) showing the probability of extinction in the wild is at least	20% within 20 years or 5 generations, whichever is longer, up to a maximum of 100 years	10% within 100 years